Nuclear Waste Disposal:
The Problem and Site Selection

by

David F. Wittoesch

A senior thesis submitted to fulfill
the requirements for the degree of
B.S. in Geology, 1984

Thesis Advisor

Colin Bull

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Acknowledgments

Special thanks are in order to the Battelle Memorial Institute for the use of their library facilities and overall hospitality.

Thanks are also in order to Dean C. Bull of The Ohio Sate University for his help and supervision of this project.

1. Introduction

There is a need for the disposal of this nation's nuclear waste. There has to be a way to isolate this waste from the biosphere, into the distant future. Isolation in a mined repository deep below the surface is the proposed method. This report examines five potential host rocks and discusses their qualitites for hosting a repository. Also, there is an evaluation of site selection criteria and the reasoning for the restrictions. Lastly, this report examines four potential site areas and three areas under, or that deserve further, investigation. These areas are evaluated to see if they meet the site selection criteria given in the report.

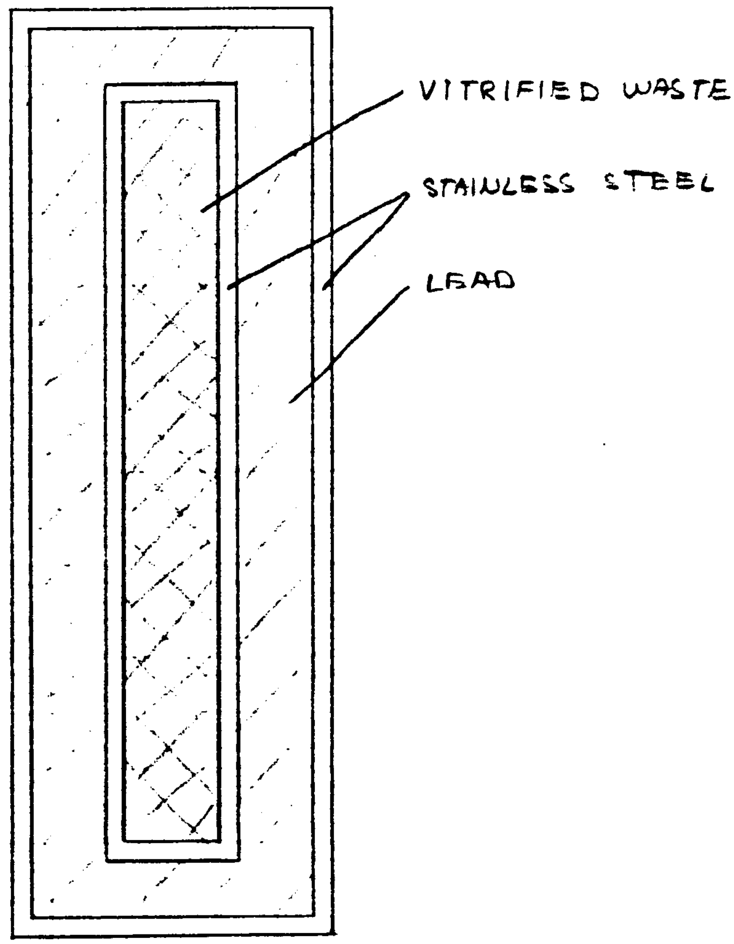
The Need for Disposal

The need to find a permanent solution for disposing of nuclear waste has been apparent since the nuclear age began, nearly 40 years ago, but now there is a sense of increasing immediacy.[1] Currently, wastes from commercial use are placed in storage pools at the reactor sites, and military wastes are being held in government storage areas. Recently, the U.S. Government and private organizations are working together to solve the problem of nuclear waste disposal or isolation. It is important that this matter be solved because the waste generated by nuclear fission can remain highly radioactive for hundreds of thousands of years. If this problem is not solved, waste will continue to build up in the temporary storage facilties.

The Waste and the Waste Canister

In a light-water reactor (the type of reactor used in the U.S. to produce electricity) the fuel used is a combination of non-fissionable uranium 238 at 97% and the readily fissionable uranium 235 at 3%.[2] When the fuel is spent, it is still highly radioactive and contains mostly uranium 236, isotopes of plutonium, and smaller amounts of other radioactive isotopes. It is proposed that this spent fuel would be reprocessed, removing most of the plutonium and uranium for further use and leaving the other fission products. It is these wastes from reprocessing, that are termed high-level wastes (HLW), that will remain highly radioactive into the distant future and are recommended for disposal deep in the ground. These wastes will be vitrified and placed in protective canisters [Figure 1] for transportation and final disposal. The canisters surround the vitrified waste by stainless steel, lead, and more steel.

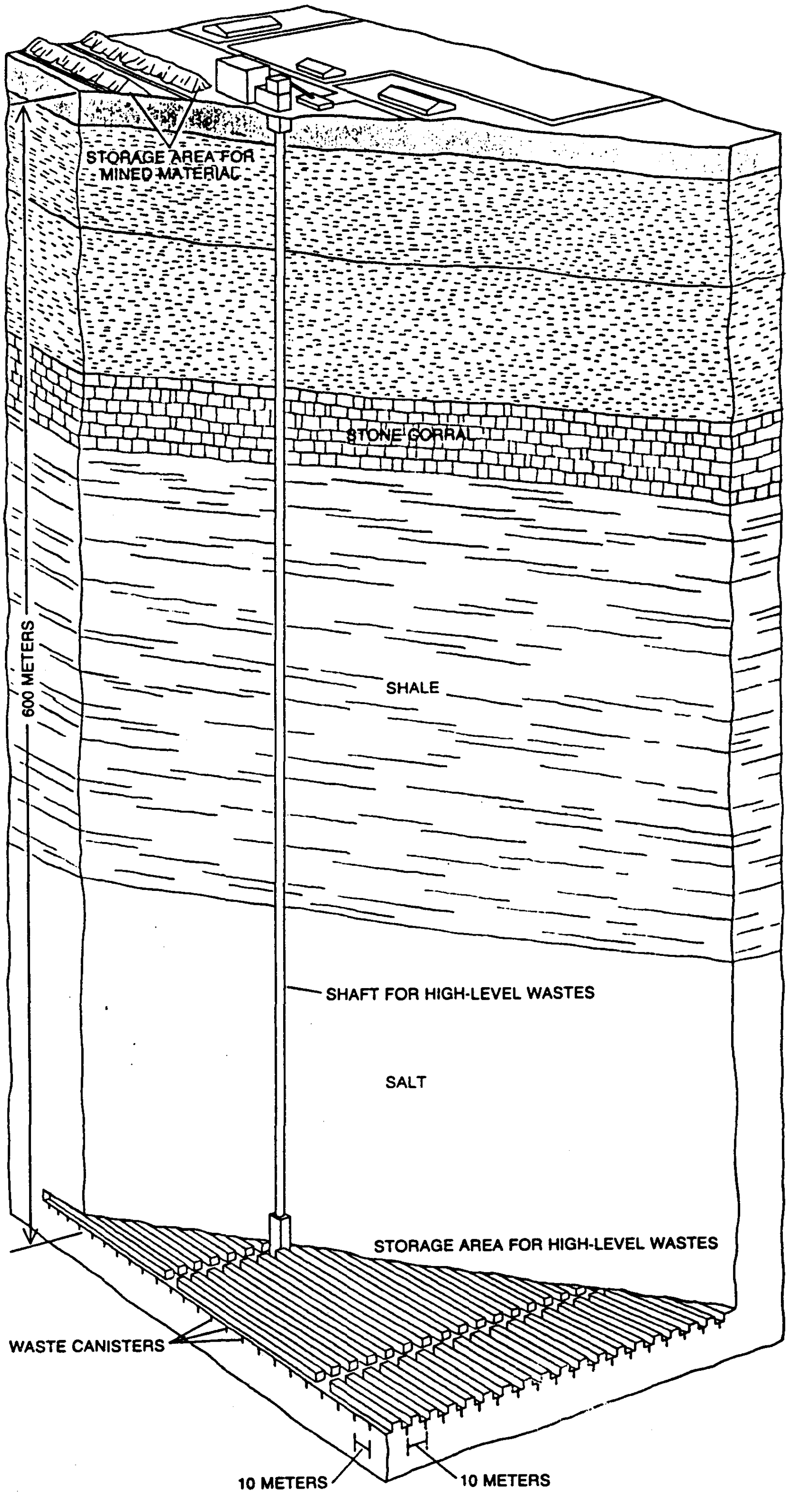
Figure 1. Basic Disposal Canister.



The Repository

Deep underground burial is at present the method favored by most nuclear power experts in the U.S. for long term storage/disposal of high-level radioactive wastes. A repository is a system of tunnels and disposal rooms with a main entrance shaft to the surface. [Figure 2] Within the disposal room floors are cylindrical holes for placement of the waste canisters. In order to dissipate the heat given off by the containers, they are spaced 10 meters apart; thus each canister would occupy an area of 100 square meters. The type of geologic medium and areas to construct such a repository facility are the concerns of the rest of this paper.

Figure 2. The Repository Structure.[3]



2. The Host Rock

There are several types of host rocks that would be suitable to construct a repository in: bedded and domal salt, granitoids, basalt, argillaceous rocks, and tuff. Each rock type has its advantages and disadvantages, but the reader should be reminded that host rock properties are site-specific and the rock-type descriptions are generalized to compensate for this.

Bedded Salt

Of potential repository host rocks, bedded salt has been the most thoroughly studied. Favorable properties which can be expected include: high thermal conductivity (which minimizes temperatures in the repository); very low permeability; the absence of moving ground water for transporatation of radionuclides; abundance of thick, widespread masses, with extensive lateral homogeneity; plasticity which permits tight closure and self-sealing at repository depths; and low cost of mining.[4]

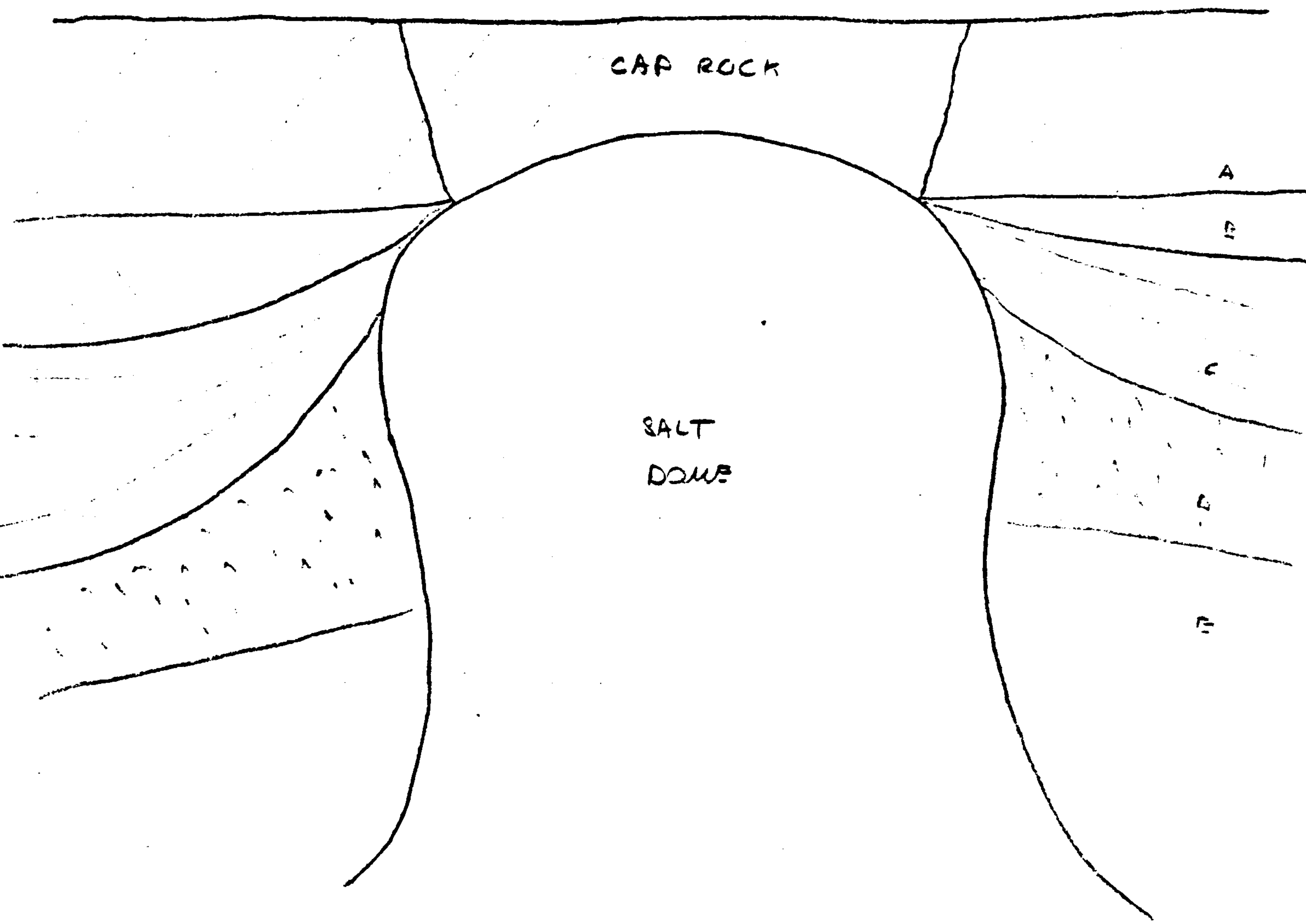
Bedded salt deposits are never pure sodium chloride. They contain varying proportions of other saline and rock-silicate minerals. Bedded salt deposits are usually laterally uniform in composition. In massive salt, water content is very low (one percent or less), but within interbeds of the formation, it can be much higher. The water associated with salt formations is a highly saturated chloride brine. The presence of this brine could cause problems for the repository because of its high corrosive activity which could eat away at the waste canisters.

The plasticity of salt, which increases with higher temperature and higher lithostatic pressures, can be an advantage in healing fractures and evacuated openings. However, the plasticity will create problems in maintaining open spaces during waste emplacement and keeping emplacement rooms open for decades if direct access for retrieval is necessary.

Salt Domes

Salt domes [Figure 3] are large masses that have been forced up through overlying rocks by the plastic flow of thick bedded salts, initially at greater depths, pressures, and temperatures.[5] The Gulf Coast region and Paradox Basin, Utah, are the more important domes of interest within the United States. Large volumes of domal salt may have uniform properties, but their borders, tops, and any internal discontinuities are non-uniform. In many ways, domal salt and bedded salts are similar, but domal salt tends to be almost pure halite. Due to their diapiric formation, the internal structure of a salt dome tends to be "homogenized." One major problem with salt domes is that the surrounding strata tend to be faulted and folded in a complex manner, which makes ground-water flow difficult to determine. Since they penetrate sedimentary aquifers, the border areas are subject to dissolution and may be surrounded by water. Despite the dynamic piercement origin of salt domes, various lines of evidence document their present structural stability.[6]

Figure 3. Typical Salt Dome.



Granitoids

Granites and related plutonic rocks are widely distributed throughout the United States. Granitoids include all holocrystalline, medium-grained to porphyritic rocks, ranging in composition from granite to diorite. Most granitoid rock bodies considered have an areal extent of hundreds to thousands of square kilometers and extend thousands of meters deep.[7] These rocks have some outstanding attributes for waste repositories because they are generally strong, structurally and chemically stable, low in porosity and permeability (but contain fractures and faults), and nearly homogenous in three dimensions over distances of hundreds of meters.

The water content of granitoid rocks is low, 1% to 2%, and is concentrated mainly in fractures and hydrous silicate minerals. High permeability rates within these rocks are in fault and fracture zones. These discontinuities can be mapped on surface outcrops, underground openings, boreholes, and inpart geophysical methods but are difficult to extrapolate to unexposed portions of the rock body. This makes locating an area within the rock mass for a repository difficult.

Of all potential repository host rocks, granitoids are most likely to be homogenous in three dimensions. Laboratory values of permeability are notably unreliable because the natural fractures are not adequately represented in laboratory samples. A crustal average of granitoid permeability is about 10 milidarcies (1 darcy = 9.61×10^{-4} cm/s or 3.03×10^{-2} m/yr),[8] which is considered good.

Granitoid rocks underlie a large portion of the continental United States mainly in the North Central and Western areas of the U.S. [Figure 4] The granitoids in the North Central area are more than 0.6 billion years old and are in a very stable area, but the Western ones are much younger and are often associated with tectonic areas (e.g. Rocky Mountains).

Figure 4. Distribution of Exposed Crystalline Rocks.[9]

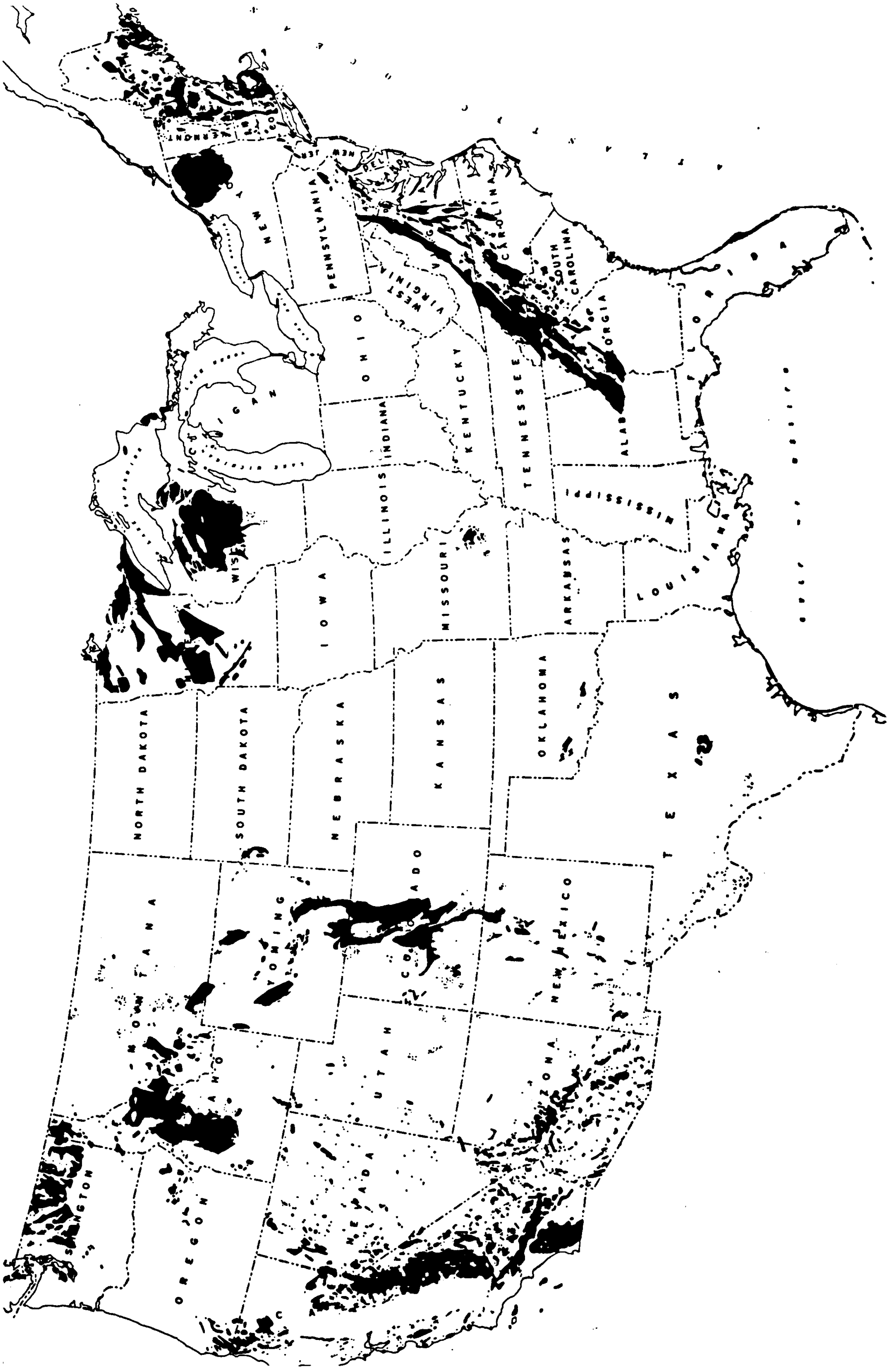
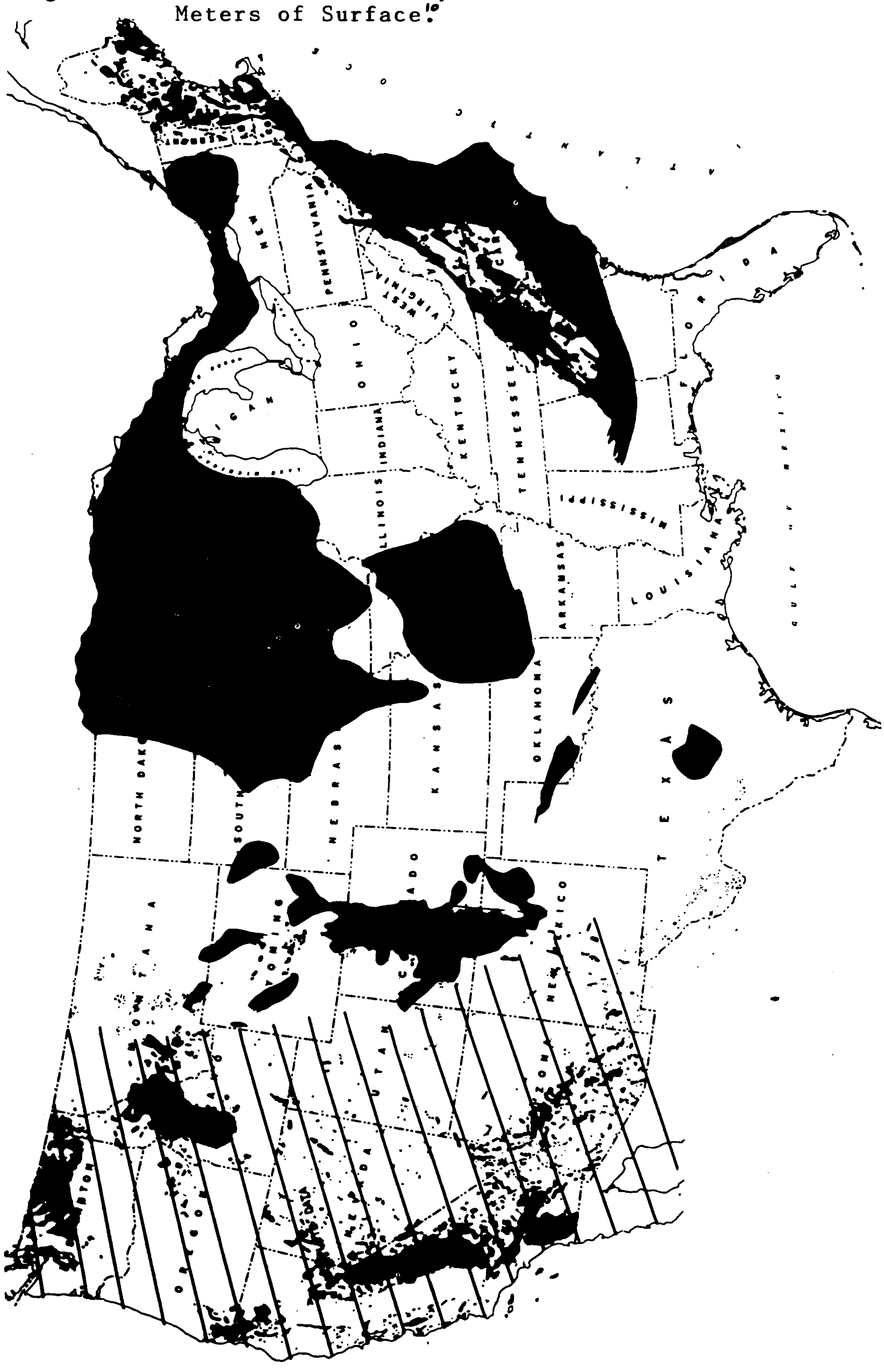


Figure 5. Distribution of Crystalline Rocks Within 1000 Meters of Surface.[10]



Basalt

Basaltic lava flows occur in thick accumulations, from 10 meters up to 150 meters, especially in Washington, Oregon, and Idaho. [Figure 6] These basaltic flows include the Columbia River basalt group. Throughout the Columbia plateau, these flows are flat-lying and virtually undeformed.

Initially, all flows had permeable tops and bottoms brecciated by flow movement, and many flows are bounded by inter-flow sediments of high permeability. With time and flow of fore water, the tops, bottoms, and inter-flow sediments become increasingly less permeable due to the deposition of secondary minerals, especially clays and beolites. A typical basalt flow has a complicated internal structure [Figure 7] with a vesicular top and a complex joint system throughout the flow. With the large number of joints, permeablility can be quite high, and in fact is the highest of the rock types considered in this report. A major reason for considering basalt for repositories is its abundance in federal land near Hanford, Washington, and the Idaho National Energy Laboratory, and not its overall characteristics.

Figure 6. Distribution of Basalts in the Western U.S."

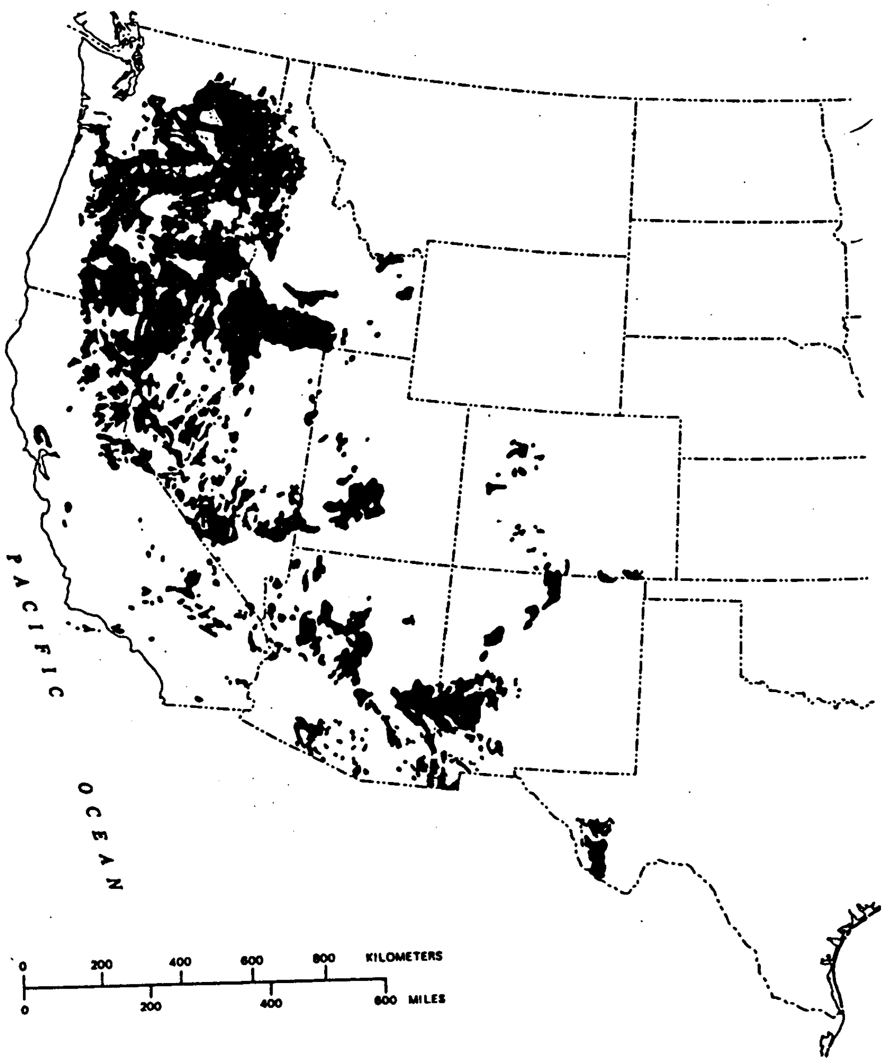
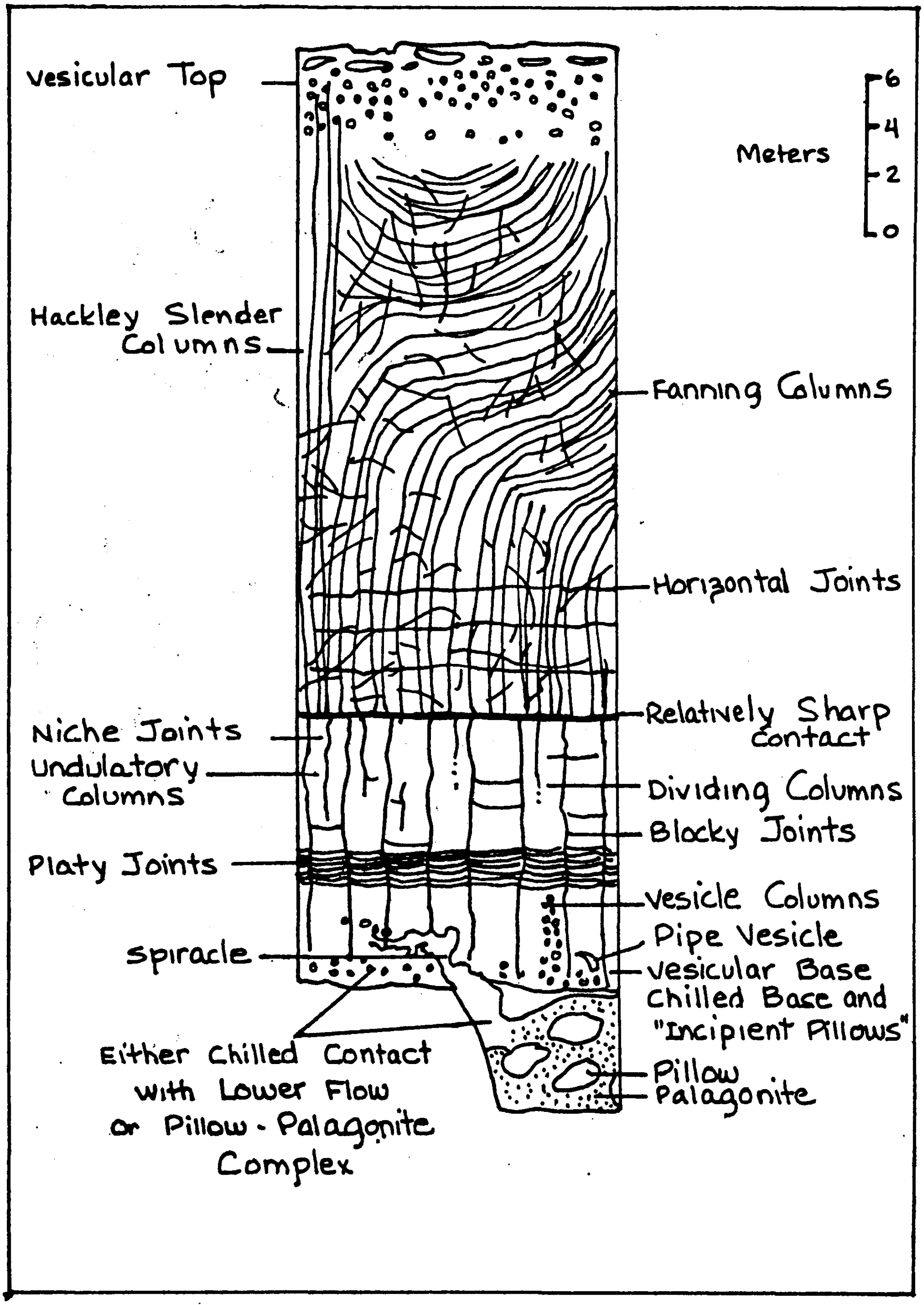


Figure 7. Structure of Typical Basalt Flow.[13]



Rhyolite Tuffs

Rhyolite tuffs, which are explosively erupted volcanic rocks, high in silica, have some favorable characteristics for repositories. Some ash-flow tuffs were so thick, typically more than 450 meters near the Nevada test site area, and hot, 600°C to 1000°C, that their siliceous glass fragments reformed plastically, forming dense "welded" tuff.

Tuffs are relatively homogenous in their horizontal dimensions, but are generally very heterogenous vertically, with each successive erupted layer differing in porosity and permeability. Generally the permeability of a welded tuff is low, but in the Nevada test site area the flows are faulted and fractured, which increases the permeability but does not necessarily rule out the possibility of their future use as a repository host rock.

Summary of Permeabilities

Permeability is the most important factor for the host rock. All of the discussed rock types have low permeabilities. The table below lists average permeabilties for some natural materials, including the host rocks mentioned in this report.[14]

Description	Permeability*
Rock Salt	7.3×10^{-3}
Granite	10
Tuff	14
Basalt	variable
Sandstone	3600
Limestone	160,000

* in milidarcies. 1 milidarcy = 9.61×10^{-7} cm/s

3. Site Selection Criteria

In order to choose a site for a waste repository, an area must meet certain geologic and other criteria. The criteria discussed in this report are visible for a nation-wide survey. They are designed to locate areas of the U.S. in which sites could be investigated. These criteria are:

- depth, thickness, and lateral extent of the rock body
- hydrologic considerations
- structural deformation; uplift, subsidence, folding or faulting
- seismic considerations
- future volcanism
- extreme erosion: fluvial and glacial
- isolation from centers of population

Depth, Thickness, and Lateral Extent of the Rock Body

The potential host rock should be present at or near the land surfaces, except for salt formations which are subject to dissolution near the surface. The near-surface requirement is to make observations and characterizations easier, particularly in the more detailed studies performed on the rock body after the site has been chosen for further investigation.

The disposal horizon should be at least 300 meters below the land surface, a depth presently believed to be sufficient to isolate the waste from such things as extreme erosion and near-surface circulating ground water.[15]

The host rock should have sufficient thickness and lateral extent to provide adequate space for a repository and to provide a zone of undisturbed rock on all sides. General considerations suggest that the minimum extent of the rock mass should be 50 km^2, except for salt domes which can be smaller because of their lack of permeability.

Hydrologic Considerations

Hydrologic conditions favorable for a desirable waste repository include: low permeability, long flow paths, and low hydrologic gradient. Permeability depends on the chosen host rock. Of the rock types considered, all have acceptable permeabilities, but the presence of faults and/or fracture zones can increase the flow through the geologic medium. Therefore, it is necessary to determine if the site chosen is faulted or fractured, and if so, to what degree.

Long flow paths are necessary. If somehow radionuclides would escape the repository, they should be trapped and have time to be diluted before they would possibly enter the biosphere. This information is difficult to obtain and would have to be determined by on-site testing.

Generally, hydrologic gradient is associated with relief and bed orientation. To have a low hydrologic gradient, the site area should be low in relief and the bed orientation should be approximately horizontal.

With respect to salt, the problem of dissolving by ground water must be examined. Since salt formations can be surrounded by a variety of rocks, it is necessary that one or more of them is not hydrologically active, because the slow dissolution process would be accelerated. For salt domes, a fractured cap rock could speed up the dissolution process.

Structural Deformation

Uplift, subsidence, folding, or faulting may adversely affect the regional ground-water flow system. Therefore, a repository should be located away from tectonic boundaries and in a region where predictable, long-term regional uplift, subsidence, or tilting will not pose a threat to repository performance.[16] The location of young and active faults are provided in Figure 8. Figure 9 shows magnitudes of vertical movement during the last 10 million years. This figure gives a general outline for the tectonically active areas of the U.S. Areas that exceed 1000 meters of vertical movement during the last 10 million years should be avoided if possible for the siting of a repository because these areas could be considered tectonically active.

Figure 8. Locations of Young and Active Faults.[17]

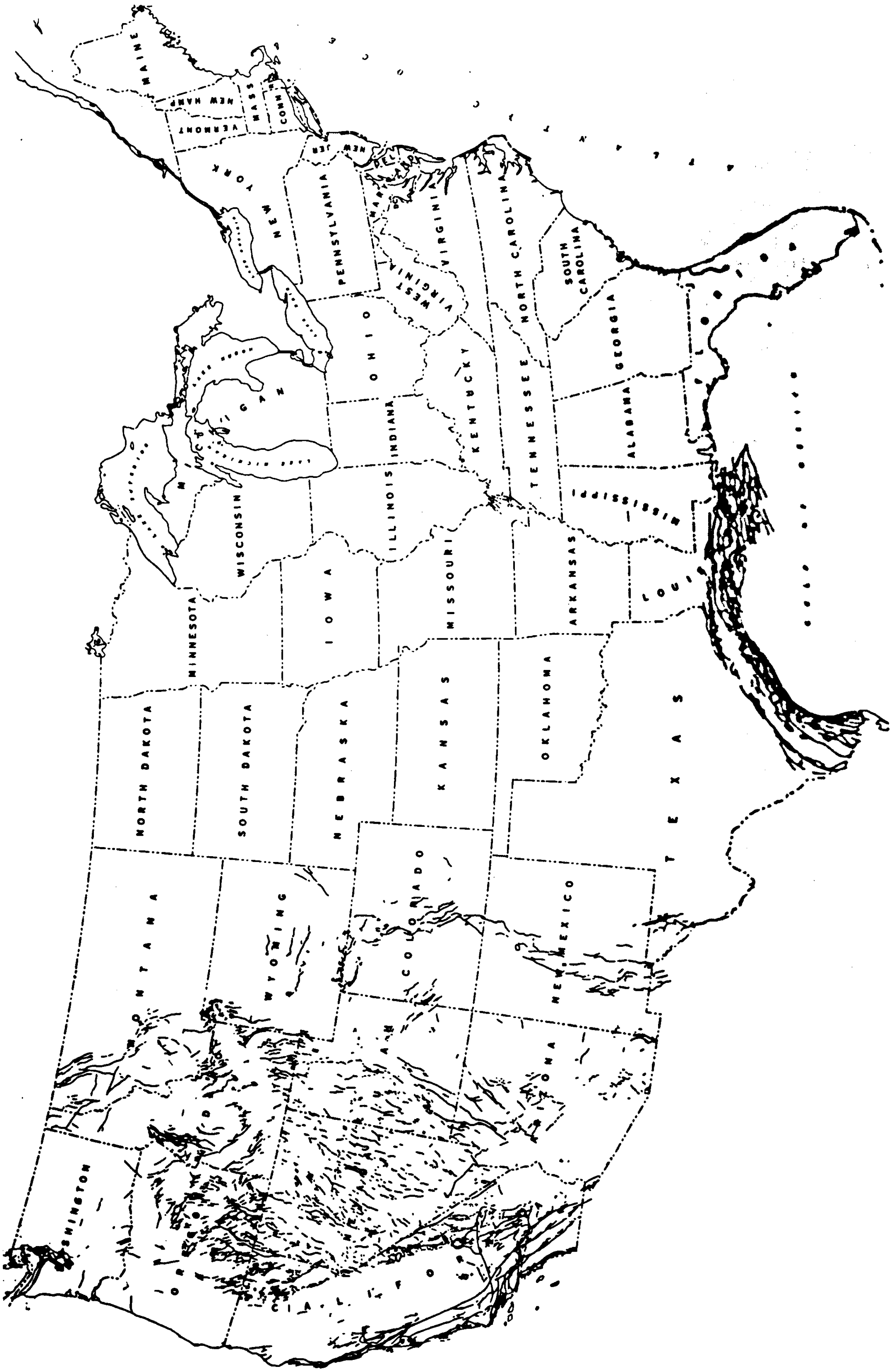
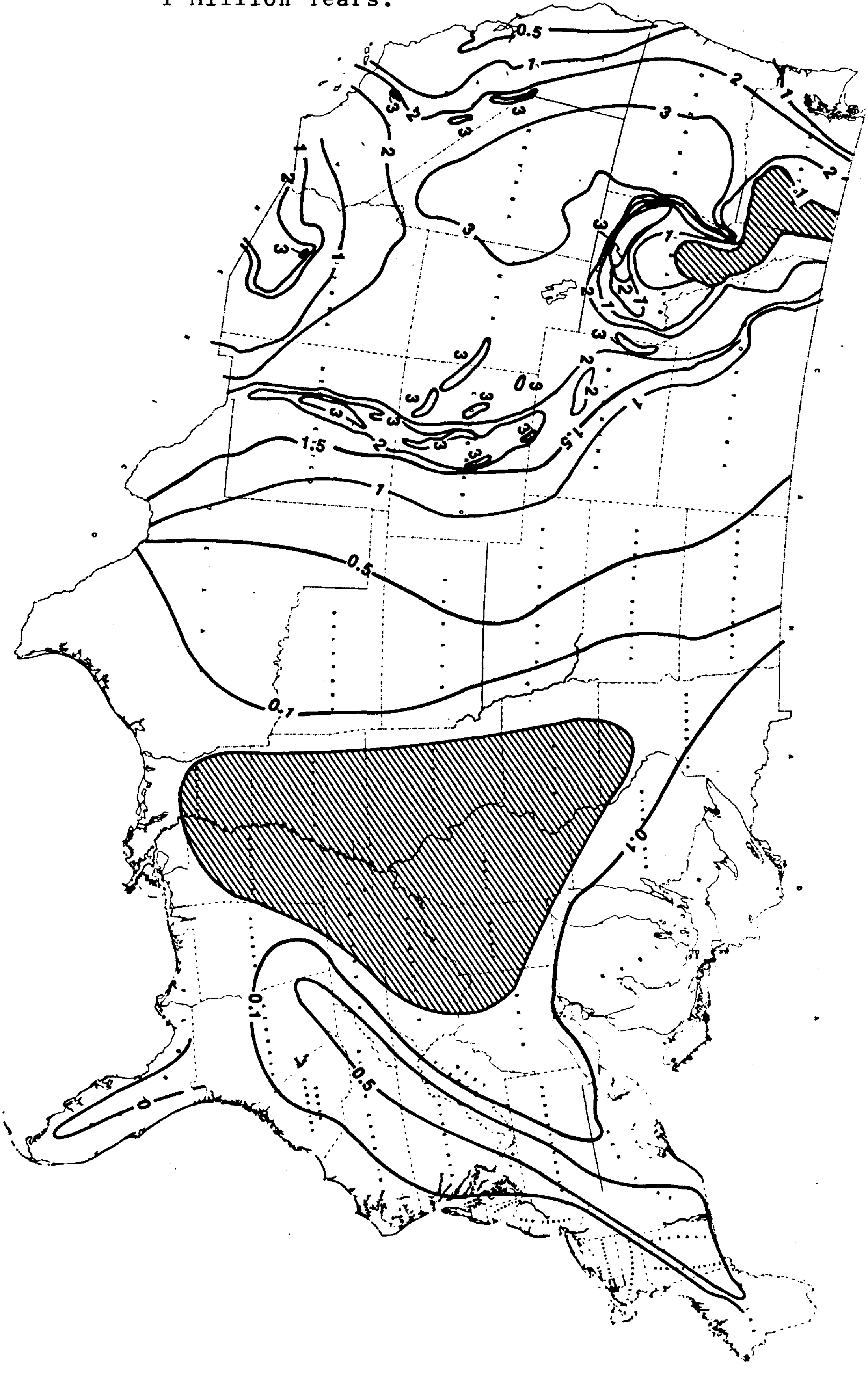


Figure 9. Magnitudes of Vertical Movement in the Last 1 Million Years.[18]



Seismic Considerations

Seismic hazards include earthquakes of vibratory or fault displacement types. Vibratory shaking is probably the least hazardous to a repository as long as the back fill material acoustically matches the surrounding medium. The main problem to consider with vibratory shaking is that it could severely damage a repository during the construction or emplacement stage. Figure 10 shows areas of the U.S. where horizontal acceleration of the ground surface could exceed 10% of the gravitational acceleration (g). The Nuclear Regulatory Commission has adopted this standard and areas that could exceed 10% g within the next 50 years should be avoided for repository siting.

The main seismic hazard is that of fault displacement. If faulting occurs during an earthquake along undetected faults through the site area, it could possibly change pathways for groundwater and increase the probability of radionuclide escape to the biosphere. The epicenters of earthquakes are usually the area of a fault. Figure 11 shows epicenters of historic earthquakes of magnitude V or greater. These areas should be avoided for repository siting.

Figure 10. Areas Where Horizontal Acceleration of the Ground Surface Will Probably Exceed 10 Percent g Within the Next 50 Years.[19]

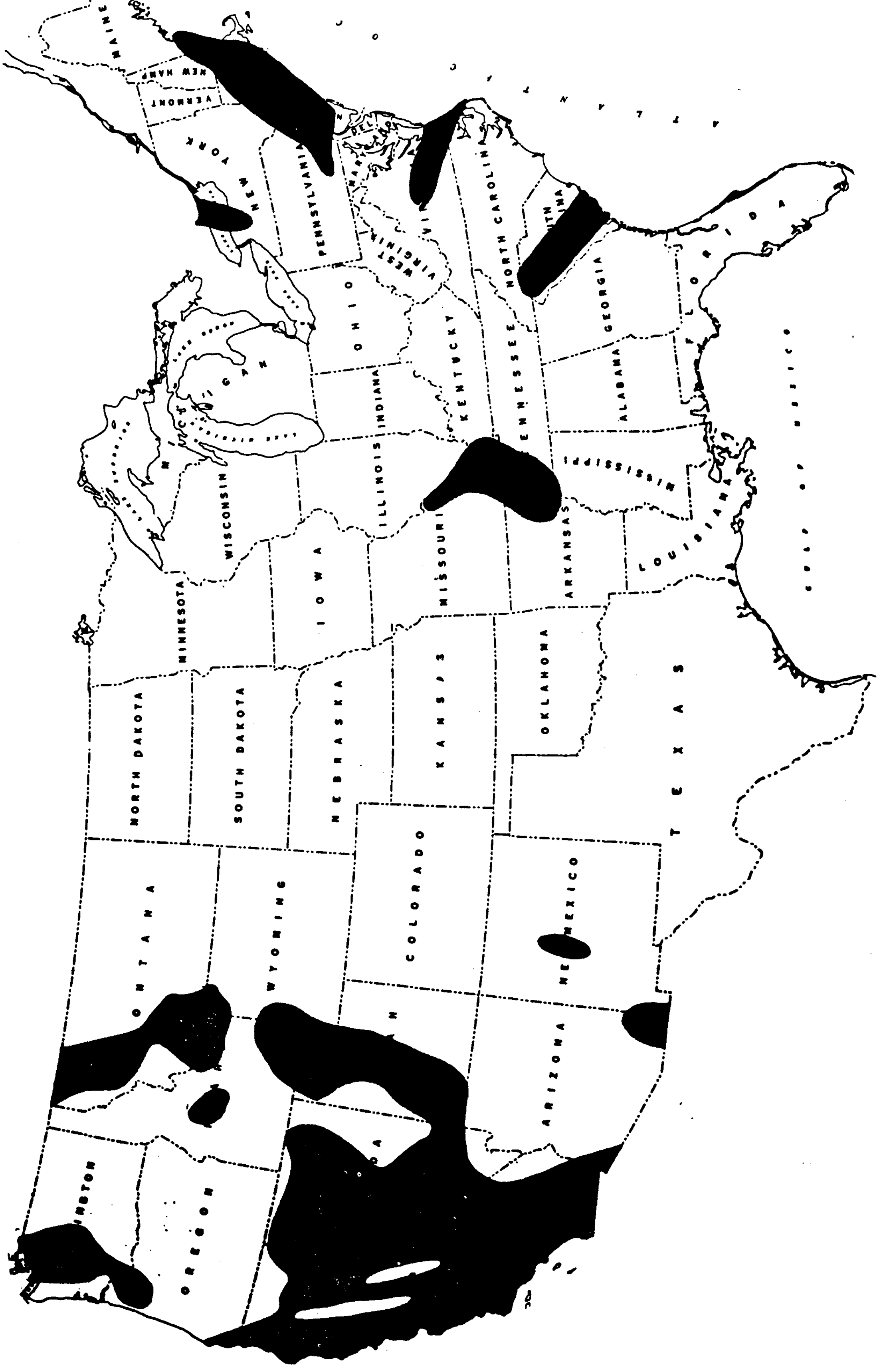
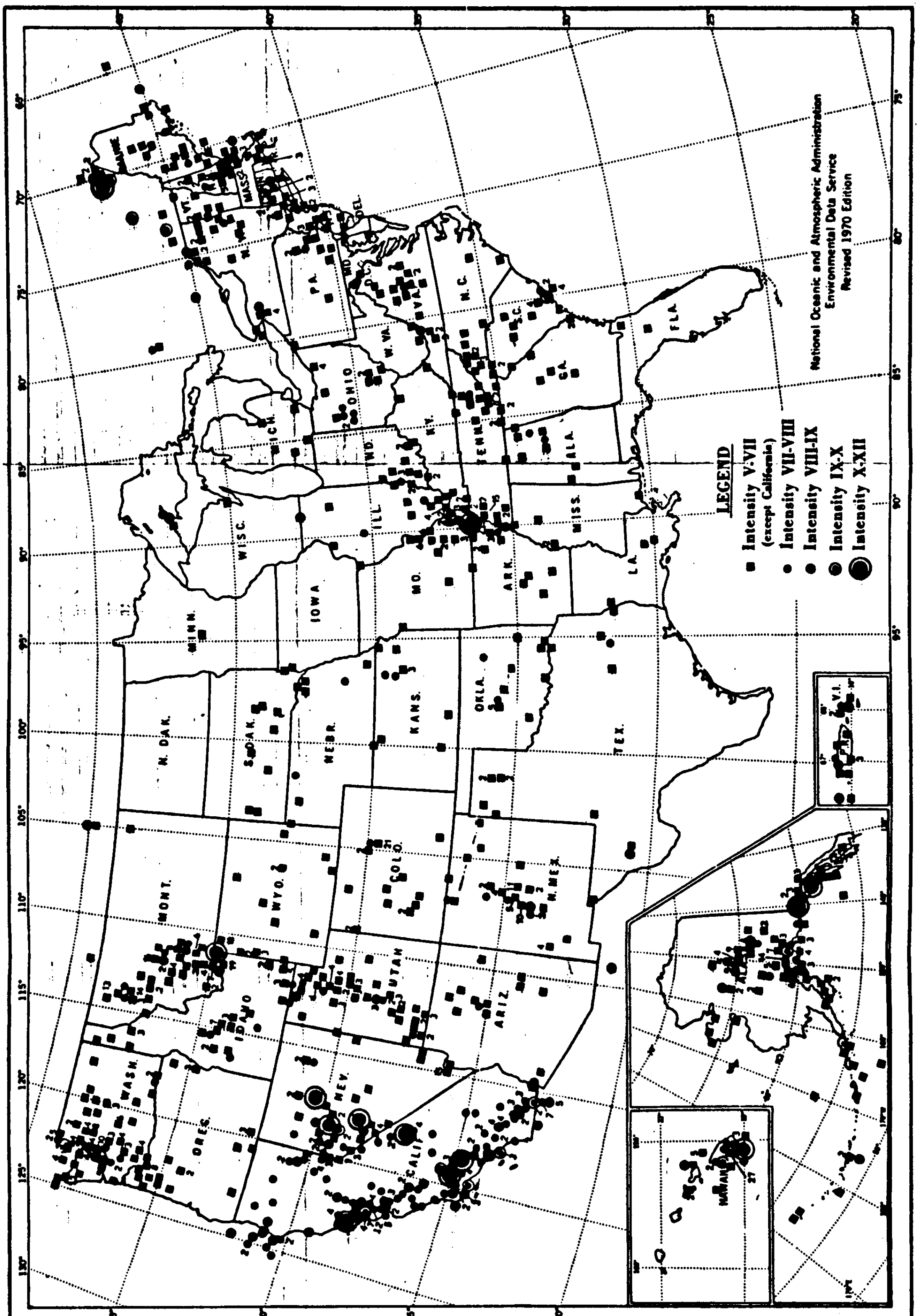


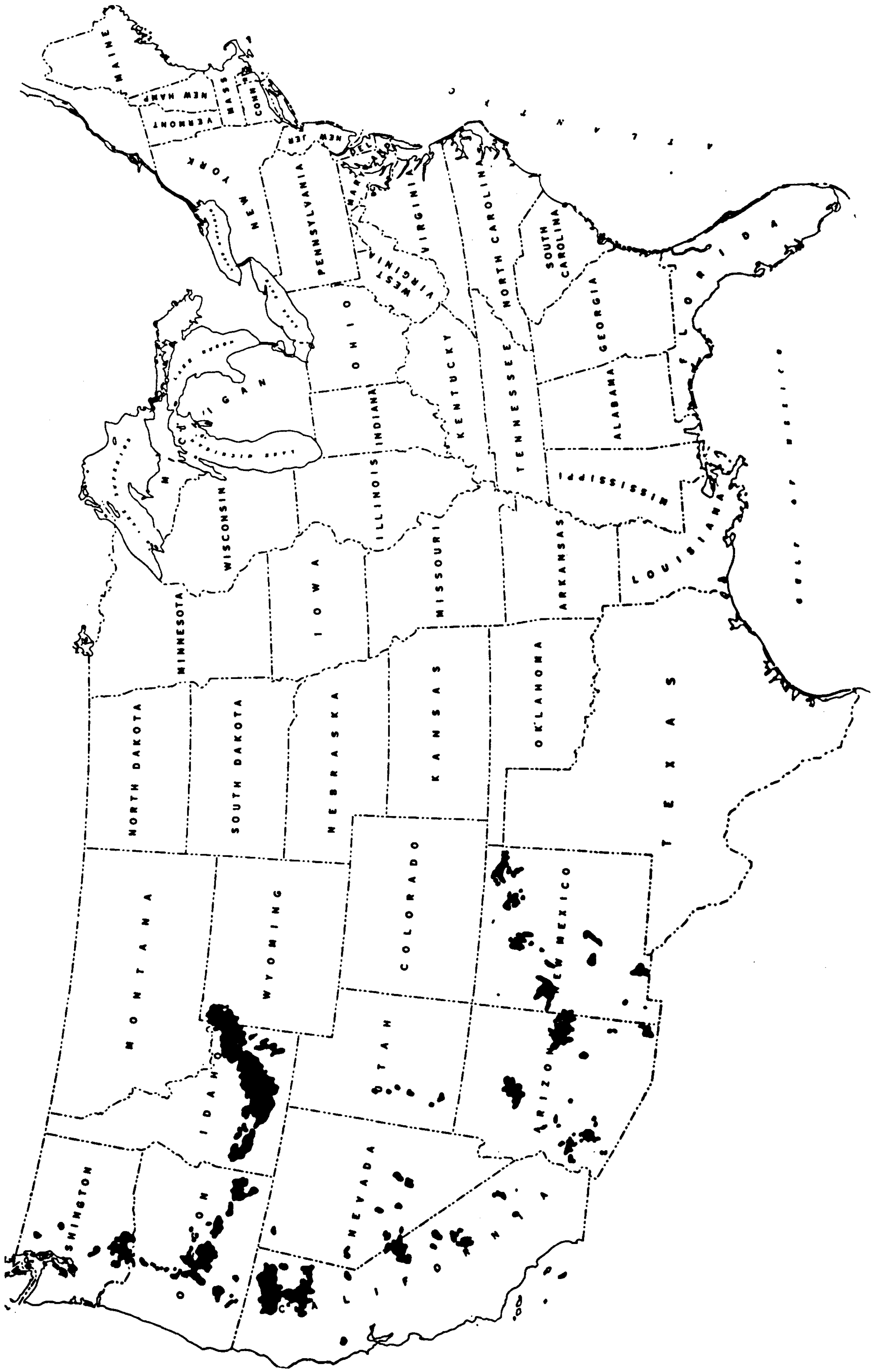
Figure 11. Epicenters and Intensities of Historic Earthquakes.[20]



Future Volcanism

Igneous activity since the beginning of the Quaternary period is known to exist only in some of the Western states. A factor in site selection is to determine probable areas of volcanism so that they can be avoided. These volcanic areas can be viewed as high risk zones. Three areas of major concern exist: the Salton Trough, Southern California; the High Cascade Range, from northern California into British Columbia; and the basin and range area. All of these areas have had active volcanism since the Quaternary and it is highly probable that it will continue during the containment period.[21] Figure 12 shows distribution of Quaternary volcanic rocks and therefore shows areas which should be avoided for repository siting.

Figure 12. Distribution of Quaternary Volcanic Rocks.[22]



Extreme Erosion: Fluvial

Areas of extreme erosion are found principally in the Western U.S. where they are largely related to vertical tectonic movement. Therefore, areas with high relief usually have high erosion rates. Extreme erosion is one reason for the 300 meter repository depth. The controlling factors of erosion rates are climate and sea level. If rainfall increases in the future, erosion rates would rise. If sea level drops, as in a glacial period, streams would cut back until an equilibrium is reached which would cause increased down cutting. For siting a repository, it is best to favor areas of low topographic relief. But low relief areas can be subject to extreme erosion. An example of this is the glacial Lake Misoula outflows, which are responsible for over one hundred meters of down cutting along the Snake River.[23]

Extreme Erosion: Glacial

Glacial periods of the past show that glaciers have the power of extreme erosion over a large area. The probability is fairly high that a glacial period equal to that of the Wisconsin glaciation will occur within the next 4000 years and a definite possibility in the next million years.[24] An average of glacial erosion over an area is only 10 meters or so and 3 meters with each glacial cycle.[25] The probability of this destroying a repository is quite low because of the 300 meter minimum depth requirement. Areas such as the Great

Lakes have had extreme erosion, but the fact that there are no "Relicit Great Lakes" suggests that extreme erosion by glaciation will occur only where extreme erosion has already occurred.[26]

Isolation From Centers of Population

It is necessary to site a repository away from centers of population. The main reason behind this point is to guard the public in the event of an accident in the transfer, emplacement, or storage which could release radionuclides directly into the biosphere.

4. Some Proposed Sites

Hanford Site, Washington [Figure 13]

At the Hanford Site, it is proposed to construct a repository in a basalt plow. The basalt at Hanford has several properties which may qualify it as a site. The plows are laterally extensive, thick, and the central portions are quite dense. At depth, the fracture zones are very thin and filled with clay. Thus, the basalt has low permeability and there is relatively little water present.

There are certain problems at Hanford that need to be solved before the area can be approved. The hydrology of the area is difficult to understand. The interbeds between the flows are virtually all aquifers. Another problem facing Hanford is that during the past 150 million years, the area has experienced earthquake activity and there are several faults which cross the area.[21]

Nevada Test Site [Figure 13]

The Nevada Test Site (NTS) is a weapons testing area located in southeastern Nevada. The main reason this area is being investigated is because it is government-owned property. There are several thick welded tuffs that could possibly host a repository, but the geology of the area is quite complex. The NTS area is faulted and folded and has a history of recent (within the last 250 thousand years) volcanism. Before this area can be approved, further investigation has to be carried out. The NTS site is in the early stage of evaluation.

Waste Isolation Pilot Plant [Figure 13]

The Waste Isolation Pilot Plant (WIPP) site is located in southeastern New Mexico. A proposed repository horizon is located within the Salado formation, a thick, bedded-salt deposit. The Salado formation at the WIPP site is approximately 500 meters thick and the proposed repository horizon is located 500 meters below the surface, near the vertical center of the formation.

The area of the WIPP site is geologically stable. There are no young faults, it is away from any past volcanism, and there is no history of seismic activity. Before a repository can be constructed at the WIPP, further studies have to be carried out on the dissolution and deformation processes within the Salado formation.

The plan at the WIPP site is to create a prototype repository for testing purposes. If all considerations check out, the WIPP will probably be the first mined geologic repository in operation.

Paradox Basin, Utah [Figure 13]

Paradox Basin is located in eastern Utah, near Arches National Park. The Paradox salt formation occurs at depths ranging from 150 to more than 400 meters below the surface. The area is relatively stable; there is no past history of Quaternary volcanism and no seismic hazards. But there are some young faults, and the area has experienced significant uplift within the last 1 million years (approximately 2000 meters). Hydrologic studies are currently under way at Paradox, and when they are finished, Paradox Basin may be approved.

5. Some Areas Under Investigation

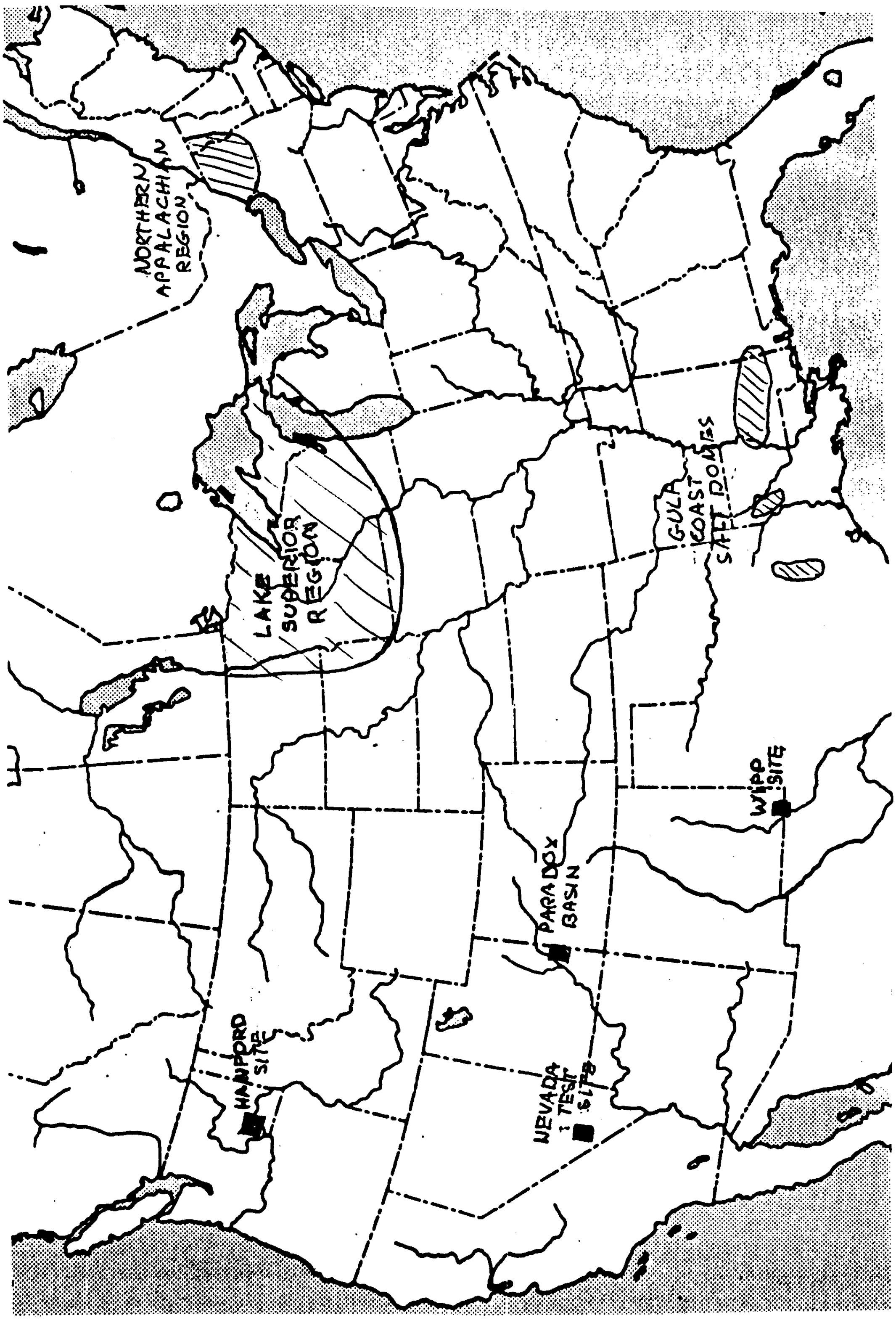
Gulf Coast Region [Figure 13]

Within the Gulf Coast region of Texas, Louisiana, and Mississippi are over 250 known or suspected salt domes. Most of these domes are associated with oil and gas deposits, so it is necessary to locate a dome that does not contain important petroleum reserves. Overall, the region is of low seismicity, tectonically inactive, and has no history of volcanism since the middle Cretatious.[28] The hydrology near dome areas is quite complex.[29] When a dome that passes the criteria is located, it will have to be further investigated for hydrologic stability.

Lake Superior and Northern Appalachian Regions [Figure 13]

These two areas are discussed simultaneously because they possess similar qualities. Throughout the research for this paper, information of any government activity into the investigation of these areas was not found. The host rock in these areas is crystalline. Both of these areas are very stable. Both feature: no known young faults; no epicenters of historic earthquakes of intensity V or higher; ground shaking less than 10% g in the next 50 years; no known Quaternary volcanics; and fairly low relief. One major problem of these areas is that they could be subject to glacial erosion because they are in the northern part of the country and have been subject to glaciation in the past. These areas should be investigated, because there is probably an excellent chance of locating a site.

Figure 13. Locations Proposed or Under Investigation.



6. Conclusions

There is a definite need for the disposal of nuclear waste. The current method proposed is isolation in a mined repository within a geologic medium. Host rock types being considered include bedded and domal salt, granitoids, basalt, and rhyolite tuff. All possess favorable qualities of stability and permeability for repository host rocks.

When siting a repository, the areas selected should meet the following criteria:

- The host rock should be present at or near the surface, except for salt formations. The host rock should have a minimum areal extent of 50 km^2, except for salt domes which can be smaller. The repository horizon should be at least 300 meters below the surface.
- The host rock should have low permeability. The ground water system should provide long flow paths. The site should have a low hydrologic gradient, which generally can be associated with areas of low relief. Rocks surrounding salt formations should not be hydrologically active.
- The area should be seismically inactive: horizontal acceleration of the ground less than 10% g over the next 50 years; and away from epicenters of known historic earthquakes of magnitude V or greater.
- Areas of Quaternary volcanism should be avoided.

The Salton Trough, the High Cascades, and the basin and range area are expected to be volcanically active within the next 1 million years.

- To avoid extreme erosion, sites should be located in areas of fairly low relief. The possibility of glaciation equal to that of the last glacial period is quite high. Glacial and fluvial erosion are not major threats because of the 300 meter minimum repository depth.

There are proposed sites under investigation at Hanford, the Nevada Test Site, the Waste Isolation Pilot Plant, and Paradox Basin. All of these areas except the Waste Isolation Pilot Plant fail to meet the criteria of this paper. The WIPP meets all criteria except hydrological considerations, which are under investigation. The WIPP will probably be the first repository in operation.

Within the United States, there are several other areas under, or that deserve, investigation. They satisfy the criteria except for the site-specific hydrologic aspects. These areas are the Gulf Coast salt dome region, which is under investigation, and the Lake Superior and Northern Appalachian regions, which deserve investigation.

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6. ibid, p. 154.

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8. ibid, p. 155.

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14. N.S. Davis, "Hydrologic Effects of Natural Disruptive Events on Nuclear Waste Repositories," Pacific Northwest Laboratory Report 2858 (Battelle Memorial Institute, 1980), p. 5.

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17. ibid, p. 16.

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